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Evaluation of conventional and renewable energy sources for space heating in the household sector

J.O. Jaber[a,*], Q.M. Jaber[a], S.A. Sawalha[a], M.S. Mohsen[b]

[a]*Faculty of Engineering Technology, Al-Balqa Applied University, Amman, Jordan*
[b]*Department of Mechanical Engineering, Hashemite University, Zarqa, Jordan*

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Abstract

Residential, space and water heating is dependent particularly upon the combustion of fossil fuels, which thereby contribute significantly to air pollution and build-up of carbon dioxide in the atmosphere. In Jordan, residential space heating accounts for about two thirds of the total residential energy consumption; with kerosene being the most popular fuel used, followed by LPG, for heating purposes. This paper is intended to evaluate space heating systems used in Jordan based on a multi-criteria analysis, using two different methods: the fuzzy sets and analytical hierarchy process (AHP). The benefits and costs of each system are considered, and the overall benefit-to-cost ratios are determined. Analyses using both methods showed that heating systems based on renewable energy, i.e., wind and solar energy, are most favorable, followed by traditional stoves burning petroleum products and finally the worst heating system is the electric heater. On percentage basis, the cost-to-benefit ratio of wind-based heating system is 4.3% and 3.9% as obtained by fuzzy sets and by AHP methods, respectively, compared to 28.5% and 18.6% for electric heating devices, under identical operating conditions.

Keywords: Kerosene; Diesel; Electricity; Wood; Renewable energy; Space heating; Household; Fuzzy sets; Hierarchy process

*Corresponding author. Fax: +962 6 4894291.
E-mail address: jojaber@yahoo.co.uk (J.O. Jaber).

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Contents

1. Introduction

Jordan lies in the heart of the Middle East and is amongst the low-income countries of the region, with an average GDP per capita of about US$2000 in 2004 [1] as compared to about US$10,000–18,000 for neighboring Arab countries, with the exceptions of Syria, Yemen, Palestinian National Authority and Egypt [2]. On the other hand, Jordan is a non-oil-producing country. It relies, almost completely, on imported oil from neighboring countries, which causes a financial burden on the national economy. In 2004, even with a relatively moderate unit price for crude oil in the international market, about US$$1.65\times10^9$ was spent on imported crude oil, refined petroleum products and natural gas [3]. This value represents approximately 15% of the GDP, 20% of the total imports and more than 41% of the domestic commodities exports. However, Jordan has abundant supplies of new and renewable energy sources, such as oil shale and solar energy. Nevertheless, crude oil has primarily dominated the Jordanian energy sector for the last four decades and still does; it has been the chief energy source for economic and social developments. Such a tough situation should make energy scarcity the main driving force behind energy saving schemes in various sectors.

In 2004, the total primary and final energy consumption were about 6.5×10^6 and 4.6×10^6 toe, respectively. The latter was distributed between transport (38%), residential (22%), industrial (23%), services and commercial (9%), and other minor sectors (8%) (see Fig. 1 [3]). The rate of energy consumption, especially electricity, is rising rapidly due to the high growth rate of population and urbanization. Residential energy requirements may vary from one province to another, depending on the standard of living, type and age of dwelling, climate conditions and availability of different forms of commercial energy sources. One of the key findings of a recent field survey conducted by the Ministry of Energy and Mineral Resources, in order to determine the energy consumption trends in the household sector in Jordan, is that space heating represents about 61% of the total energy consumed in the residential sector [4].

Thus any action to improve energy efficiency in this sector should take into account the need for analyzing and studying different ways of space heating and opportunities to reduce the envelop energy losses, while simultaneously maintaining inside of the house comfortable. Many researchers addressed some prospects of energy savings in the residential and commercial sectors, and the main conclusions were to improve thermal insulation of buildings, increase dependence on renewable energy sources and to conduct

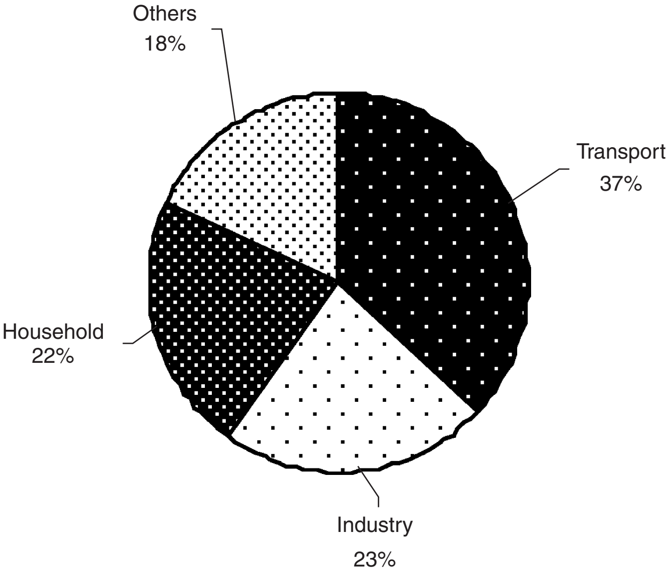


Fig. 1. Distribution of final energy consumption in 2004.

comprehensive public awareness campaigns, aiming to enhance the utilization of proven more effective, higher efficiency applications and techniques [4–7].

In light of the recent survey findings and other local studies with respect to space heating, this paper is intended to evaluate the different space heating systems used by households in Jordan. Due to the limitations of financial evaluation methods for energy saving schemes, the fuzzy logic method and the analytical hierarchy process (AHP) methods will be used as a practical approach for addressing other issues, such as reducing atmospheric pollution, beside the financial one. It is stressed that it is not the aim of this study to focus on critical issues such as those relating to the combustion of different fuels employed in the residential sector, rather general information is derived to indicate the overall problem accompanied with using various types of heating systems.

2. Space heating systems in Jordan

The different types of energy sources used in urban and rural households in Jordan are shown in Fig. 2 [8,9]. In urban areas 99.6% of dwellings use both electricity and LPG fuel, which are rated as the highest. On the other hand 8.4% of the residents used firewood, which is rated as the lowest. In rural areas LPG is rated as the highest energy source where it scored 98.9%, and diesel fuel is rated the lowest with a value of about 14.3%. The percentage uses of different fuels for heating purposes are shown in Fig. 3. Kerosene is the highest, it represents 63.2% and 75.0% among the fuels used for heating in both urban and rural areas, respectively. LPG has the second highest rating with about 30.2% for urban and 20.5% for rural regions [6–9]. Most households use traditional portable kerosene stoves, followed in popularity by fixed kerosene or diesel stoves and the new LPG heaters, especially in low-income categories. Recent surveys indicate that about 97% of households

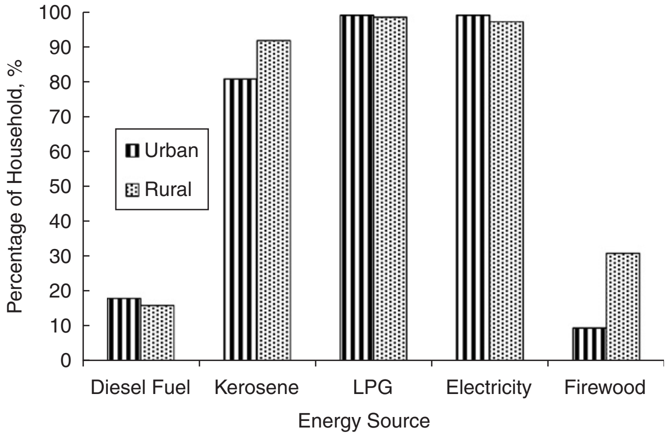


Fig. 2. Residential use of different energy sources in urban and rural areas.

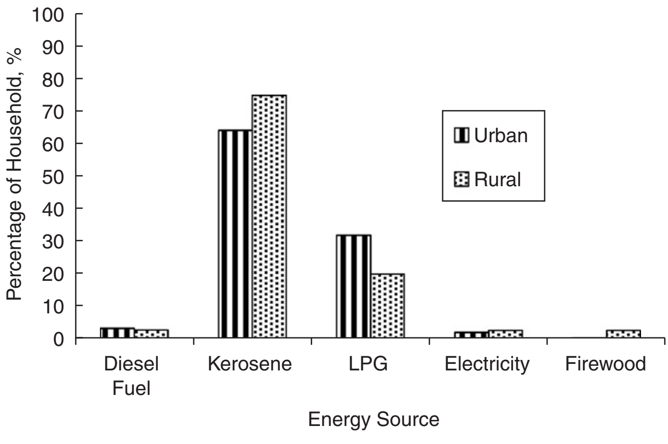


Fig. 3. Use of different fuels for space heating in urban and rural areas.

use LPG for cooking and 28% and 14% use it for space and water heating, respectively. The use of electricity for space heating, however, should be deprecated.

Fig. 4 shows the penetration of various types of household space heating systems for years 1986 and 1996 in Jordan. It is obvious that there is an overlap between systems being employed [6]. This can be explained as more than one type is sometimes used in a single house. Moreover, there is a tendency for households to use either small kerosene or LPG heaters as a back-up for each other, or when the central heating system is turned off. Also, the rapid expansion in the use of LPG heaters was due to the unit price increase of the kerosene, under the energy adjustment program, initiated in 1993, in order to reduce fuel subsidies from the government and to reflect more accurately true economic costs. Meanwhile, with higher kerosene prices and the high growth rate of the population, LPG, which is at present subsidized by the government, has emerged as the most attractive fuel available in Jordan for domestic use, due to its reliability and cleanliness compared with

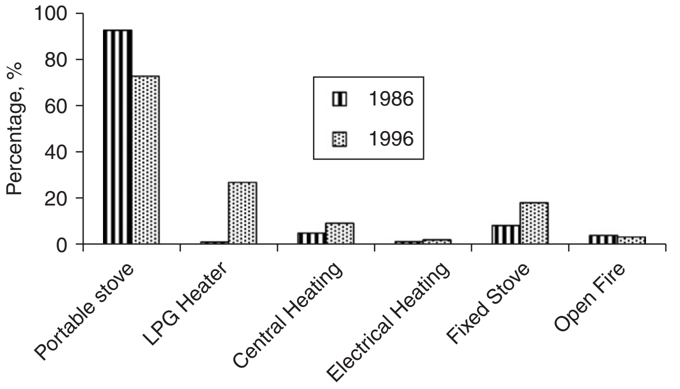


Fig. 4. Percentage of households employing the stated heating system.

kerosene. Also, because of the relatively low diesel fuel unit price compared with those of other available alternative fuels in the local market, diesel-fuelled central-heating systems for space heating have become more popular during the last decade. However, such modern systems are found in wealthy districts, and houses equipped with central heating represent only a small portion of the total housing stock, in both urban and rural areas: 11.8% compared with 7.3% in the urban districts, and 2% compared with 0.5% for rural regions, for the years 1996 and 1986 [6]. Although, there is an increase in the percentage of dwellings that are equipped with central heating systems in both urban and rural areas, most households still use traditional portable un-vented kerosene and LPG stoves as well as fixed vented heaters. There is a negative correlation between the use of kerosene and family income: households with low income use it preferentially because they rely on less expensive kerosene burning devices that can be employed simultaneously for space heating and cooking. Unvented combustion appliances, employed to provide space heating, produce high levels of combustion byproducts that often exceed acceptable concentrations, degrading indoor air quality and causing unnecessary exposure to toxic gases such as carbon monoxide.

3. Electricity and energy pricing policy

Ideally, this should ensure both, the most efficient use of energy and simultaneously protect consumers from the volatility of short-term fluctuations. Moreover, to facilitate planning, it should provide an indication of what energy taxes will be imposed by the government over a reasonably long-term time scale. The current methodology of pricing petroleum products is based on setting each product's price at the retail price, i.e., for final users, setting the transfer price for crude oil retroactively and deriving implicit tax for each product based on the difference between the retail price and the full production and distribution cost. The major disadvantage of such a methodology is the confusion caused by mixing the fiscal objectives with policy intentions. Pricing policy objectives should include identifying the optimal selling price for a product, its import cost and external costs such as incurred by road usage and pollution. The tax rates should be set at a fixed level for each specific product, so that revenues for each product are known and can be predicted

easily. A transparent pricing procedure for petroleum products must be adopted that should serve both the economic and national interests. Crude oil prices should be linked to an import parity formula, i.e., the total price is the sum of the international market unit price, insurance and transportation and handling costs. Prices of petroleum products should be established under the same formula: these prices will be that at the refinery gate for each product. The retail price should also include any added costs, such as distribution and marketing commissions, fixed taxes and other fees and service charges.

A uniform electricity tariff was introduced in 1984, and the Long Range Marginal Cost (LRMC) approach was used to establish the relative rates that each consumer sector must be charged. The tariff must exceed the LRMC in order to cover the full utility operating expenses. Such a tariff must provide sufficient financial returns to encourage further investments in the electricity supply industry. The government's aims of implementing a uniform tariff are to reduce the administrative cost and complexity associated with non-uniform tariffs, provide equity to the public and decrease the incentives for movements of population to urban areas. However, such a tariff system is not the optimal one, because the introduction of additional government's subsidies to reduce urbanization is costly: subsidies encourage greater consumption and discourage efficiency. It is much better for the government to provide direct help to those low-income consumers, who may not be able to afford to pay the actual cost of electricity, rather than subsidize the whole of society. Incentives to modify the customers' actions are an important element in any tariff structure. They should provide consumers, who have the relevant knowledge, with the motivation to reduce their electricity bills. This can be accomplished if there are sufficient relative reductions in the tariff to encourage consumers to modify their consumption behaviors, e.g., to use less electricity during high-demand periods. In the case of Jordan, with its high rate of growth in demand for electricity and a low ability to raise capital, it is critical that the tariff should be designed to reduce electricity usage during the peak demand period by shifting the consumption, if it is necessary, to off-peak hours. Such an approach will reduce (i) the need for new generation units, (ii) the need for the expenditure of hard currency for oil imports and (iii) environmental pollution.

Since 1993, the government implemented an energy sector adjustment program in coordination with the International Monetary Fund and World Bank. This program aimed at restructuring the sector financially and institutionally in order to achieve sustainable growth and development. As part of this program, the government raised the unit prices of petroleum products and electricity, on annual basis, during the last 10 years (Fig. 5). In 2005, the retail prices were increased two times; the last one was in June 2005, with highest ratios being for kerosene and diesel. The recent prices adjustment was in April 2006, when the government had announced the new retail prices' of different energy forms. Kerosene, diesel and LPG witnessed a sharp increase as can be seen from Fig. 5. The main reason behind such decision is removing governmental subsidy from various energy forms and ensure the full coverage of the economic costs involved. But the government postponed increasing the prices of electricity in order to enable consumers in the local market to absorb this price shock and sooner or later prices of electricity and other strategic commodities will be increased. Again, the highest rate of increase was in the unit price of kerosene, which is widely used for space and water heating in the household sector especially among low income families.

Recently, natural gas is being imported from Egypt and used for power generation in the Aqaba thermal power station. By the end of this year 2006, it is planned that natural gas

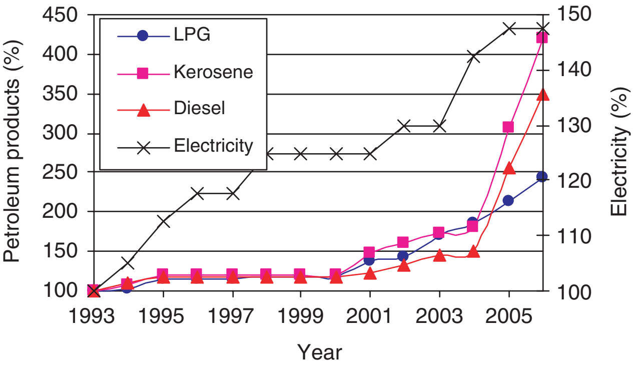


Fig. 5. Increasing prices of various energy forms used in the residential sector.

will be available to power plants in the northern region and some large industrial facilities. But it will not be available for residential consumers before 2012 due to large capital investments required for distribution networks. If the price of natural gas is set to reflect the price of alternative fuels, it can be expected that natural gas will have an increasing share of future energy consumption in all sectors, including the household. However, considerable upfront investments need to be made to enhance this development, which might be a barrier for the conversion, especially in the residential sector. Thus, available alternative energy sources, such as renewables, should be developed and utilized where they prove to be attractive and feasible, especially for low-temperature applications, e.g., heating and drying.

4. Employed methodology

This article is intended to evaluate two different methods for space heating systems used in Jordan based on a multi-criteria analysis: the fuzzy sets and AHP. The following sections summarize main features of these methods.

4.1. Fuzzy sets method

The fuzzy set logic method has been effectively used in many types of complex multi-criterion problems [10,11]. These include energy consumption, space control decision making, subway systems and other industrial fuzzy control processes, such as fuzzy conditioner, fuzzy washing machines, fuzzy toasters and fuzzy vacuum cleaners.

Fuzzy logic theories are based on introducing a special notion of relativity to compare fuzzy, vague or ambiguous objects [12,13]. If p and q are two variables defined on a universe U, and $f_q(p)$ and $f_p(q)$ are two pair-wise functions defined as the membership functions of q with respect to p and p with respect to q, respectively, the relativity function $f(p/q)$ is defined to measure the membership value of choosing p over q, as shown in Eq. (1).

In the case of more than two variables, then variables $p_1, p_2, \ldots, p_i, p_{i+1}, \ldots, p_m$ are defined on the universe, U, collected on the set $s = \{p_1, p_2, \ldots, p_i, p_{i+1}, \ldots, p_m\}$, and form a

comparison matrix, C, of relativity values $f(p_i/q_i)$; where $i, j = 1, 2, \ldots, m$ and p_i and q_j are defined on the universe U. This matrix (m, x, n) will be used to rank the different fuzzy sets.

$$f(p/q) = \frac{f_q(p)}{\max\left[f_q(p), f_p(q)\right]}, \tag{1}$$

$$C'_j = \max f(p_j/s). \tag{2}$$

In order to determine the overall ranking, the largest or smallest values in each of the C matrix are found:

$$C''_j = \min f(p_j/s), \tag{3}$$

where C'_j or C''_j is the membership ranking value for variable j. The maximum and minimum functions are used when objects are ranked in terms of their benefits and costs, respectively. Detailed presentation of the fuzzy sets methodology can be found in recent studies [14,15].

4.2. AHP

The AHP has been effective in structuring many types of complex multi-criterion problems. For example, it has been applied to business decisions [16], evaluation of energy systems [17], water desalination [18], choosing areas of research and development programs [19], estimation of the economy's impact on sales, the problem of traffic congestion, real estate investment [20] and water policy [21]. The AHP enables decision makers to structure a problem in the form of a hierarchy of preferences through a series of pair-wise comparisons of relevant factors or criteria. Similar to the fuzzy sets method, applying the AHP approach to cost-to-benefit analysis requires separating costs from benefits and the construction of separate hierarchies for benefits and costs. In order to establish the priorities of the alternatives in both benefits and costs hierarchies, pair-wise comparisons are necessary. The scale that was developed in 1980 by Saaty for pair-wise comparisons was used. For more step-by-step details on this methodology, the reader can obtain more information in previously published work by the authors [18,22].

There are five basic steps in applying the AHP in practice: (i) structuring the decision hierarchy, (ii) collecting data by pair-wise comparisons, (iii) checking consistency of material judgments, (iv) applying the eigenvector method to compute weights and (v) aggregating the weights to determine a ranking of decision alternatives. The primary advantage of the basic AHP approach is its simplicity; once the criteria are agreed upon, and supporting data are collected for each alternative, the AHP analysis can be processed. The category weight is used to adjust the overall weight of each benefit criterion. After evaluating the alternatives with respect to the benefit and cost criteria, an overall benefit weight and cost weight are determined for each alternative. Benefit-to-cost ratios are formed to facilitate the final selection of alternatives. Sensitivity analysis can be used to test the solution and examine how changes in criterion weights would alter the final weight and ranking of the individual alternatives.

5. Analysis and discussion

The decision regarding the selection of an optimum space heating system in Jordan was evaluated according to its benefits and costs using both fuzzy sets and AHP methods. The benefit and cost hierarchies were considered separately, and benefit-to-cost ratios were obtained. The benefit and cost hierarchies were constructed; the benefit hierarchy includes all possible benefits that may be derived from various space heating systems. The benefit criteria at level 2 include efficiency, reliability and availability of fuel, national economy, social benefits and safety.

On the other hand, the cost criteria at level 2 are costs of appliance or heating system, fuel, maintenance and service, auxiliaries and environmental constraints. The third level of the benefit and cost hierarchies represent all possible space heating systems in Jordan. The selection of these alternatives was based on the results of the recent survey on energy consumption in the residential sector. These alternatives are central heating, traditional diesel and kerosene stoves, portable LPG heaters, electric heaters, fireplace, and wind- and solar-powered heating systems. The latter represent the most possible renewable energy sources that can be employed for such applications in Jordan.

In order to establish the priorities, i.e., weights, of the alternatives in both the benefit and cost hierarchies, pair-wise comparisons were necessary. The related scoring and relative weights for the different space heating systems with respect to the benefits and costs for fuzzy sets and AHP methods were determined. The relative weight of each benefit and cost criterion was obtained for all selected systems. The relational scoring for all benefit and cost criteria with respect to each other was calculated for both methods, as well as the relative weight scoring of each benefit and cost criterion. An overall relative weight factor was then obtained from these results. These weights are of the overall relative properties of the eight different space heating systems against the six benefit criteria and the five cost criteria.

In light of cost analysis, and based on the overall costs, AHP method shows that the fireplace, using wood, is the least expensive system (about 6%), followed by renewable heating systems (7%) and traditional stoves (10–12%), and finally the central heating system is the most expensive one (about 24%). Similar results are obtained by the fuzzy sets method, where the fireplace is the least expensive system (about 3%), but the electric heater is the most expensive system (about 31%), as shown in Fig. 6. These results are in full agreement with those obtained from the most recent energy survey of the household sector.

Usually, dwellings equipped with central heating systems are limited to those in wealthy districts, which represent only a small portion of the total housing stock, due to the high initial cost of central heating systems. The majority, i.e., 83%, of dwellings still depend on kerosene as the prime source of energy for space and water heating [6,23]. This can be attributed to the fact that poor families use the less expensive kerosene burning devices that can be employed simultaneously for cooking and space heating. Whereas firewood usage is almost negligible in urban areas and limited to preparing barbecues, in the suburbs, especially by the bedwenes living in tents, it is still used for heating and cooking purposes. Finally, due to the relatively high cost of electricity, only about 2% of electrified houses have an electric hot plate or electric heater, which is used for space heating and/or cooking. The use of electricity for space heating in Jordan should be deprecated.

Fig. 7 demonstrates results of the benefit analysis of the AHP method. Whereas central heating is the most beneficial system (about 23%), it is followed by renewable powered

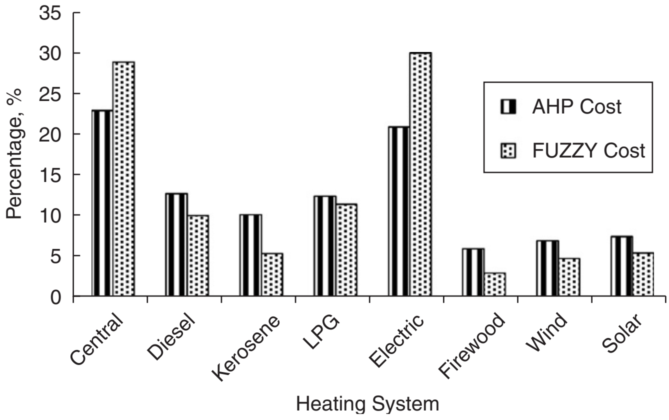


Fig. 6. Comparison of costs for fuzzy sets and AHP.

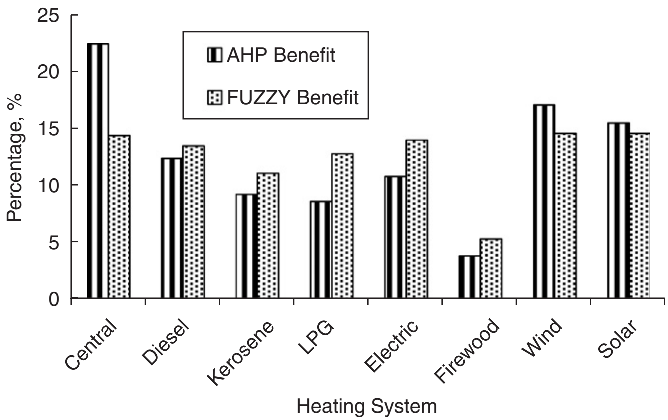


Fig. 7. Comparison of benefits for fuzzy sets and AHP.

heating systems (15–17%) and traditional stoves including LPG portable heaters (9–12%). Electric heating systems ranked fourth before the fireplace, which is the least (about 4%). Again, the firewood heating system is the least beneficial (about 6%), while wind- and/or solar-based heating systems are highly beneficial (about 14%) according to fuzzy sets method. However, solar energy is not harnessed via solar water heating systems for space heating, and its use is limited to the supply of domestic hot water needed for nearly one quarter of households all around the country.

This pattern of energy consumption, for space heating, combined with the high growth rate of the poor population, has serious health and environmental implications, because the combustion of kerosene, and to less extent LPG, is associated with high levels of indoor air pollution [6]. Even so, LPG is considered as a highly efficient and clean fuel compared with kerosene or diesel fuel and the most likely hazards associated with employing LPG stoves in households are due to gas leaks and direct burns from open fires, which also occur with kerosene stoves.

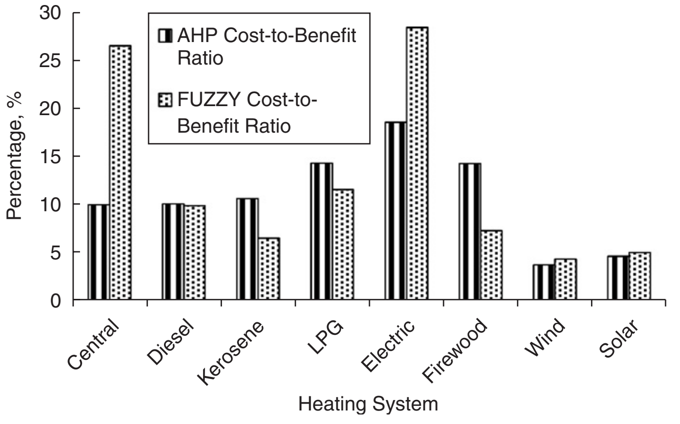


Fig. 8. Comparison of cost-to-benefit ratios for fuzzy sets and AHP.

To summarize, the overall cost priorities were divided by the overall benefit weights to obtain cost-to-benefit ratios for both fuzzy sets and AHP methods, as shown in Fig. 8. A wind-based heating scheme is the cheapest system (4.3% for fuzzy sets and about 3.9% for the AHP) and electric heaters are the most expensive (28.5% for fuzzy sets and 18.6% for AHP). But it should be remembered that the most appropriate wind-based heating system for local conditions, including wind pattern and speeds, still requires detailed technical investigation and thoroughly economic evaluation in order to establish its techno-economic feasibility.

It is worth mentioning that in a recent study [24], it was found that the lack of awareness of these technologies and their potentials, due to the absence of concerned governmental agencies, is an extremely important factor about the existence of alternative solutions for space and water heating as well as involved costs for implementing them. Equally important is the lack of financial incentives and funds to promote renewable energy utilization in all sectors of the economy [4,25]. Thus, the required capital investment should be allocated by the government to exploit such a free and clean resource, because renewable energy sources are not competitive in Jordan under the current energy pricing policy: there is no special arrangement or privilege for investors to encourage their harnessing.

6. Conclusion

Space heating in Jordan accounts for about 61% of the energy consumed in domestic premises and nearly 14% of total national annual energy demand. Thus, this paper focuses on evaluating seven different space-heating systems that have great potential in the local market. It also presents some background that can be helpful to decision makers in strategic assessments of future energy plans aiming to enhance efficiency and reduce dependence on imported energy as well as pollutant emissions. Both methods, the fuzzy sets and AHP, allow taking into account non-financial aspects when evaluating heating systems. Considering cost-to-benefit analysis, and based on the two methods, wind- and/or solar-based heating systems are the most inexpensive, followed by traditional stoves, which

are mostly used at present, and the electric heating system is the most expensive. Although the use of solar energy for domestic water heating is quite popular in Jordan's residential sector, i.e., about one fifth to a quarter of total number of dwellings, especially in urban districts, had been fitted with solar water heaters, none of them employ it for space heating. In case of wind energy and based on the developed criteria, it is found that a wind-based heating system is the most desirable scheme to be used in Jordan. Equally important is to note that wind speeds are the highest during winter season, when heating is mostly required in Jordan. Thus, it would be wise if the government begins to rely more on renewable energy, where their use is financially attractive, in order to reduce the dependence on imported expensive sources of energy. Research and development in this field must be given the highest priority. Finally, authors believe that the current analysis can be applied to other neighboring Arab countries with similar conditions, i.e., the Palestinian Authority, Syria and Lebanon.

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